

# **Synthesis and Characterization of Titanium Dioxide Nanoparticles in Wood Protection Application**

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Science with Honours (Resource Chemistry)

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Nanoparticles in Wood Protection Application

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## **DECLARATION**

I hereby declare that this Final Year Project 2015 dissertation is based on my original work except for quotations and citations, which have been duly declared that it has not been or concurrently submitted for any degree at UNIMAS or other institutions of higher education.

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## LIST OF ABBREVIATIONS

AWPA	American Wood Protection Association Standards
Ag	Silver
C	Carbon
CCA	Chromated Copper Arsenate
EWC	Engineered Wood Composites
EDX	Energy Dispersive X-ray
FTIR	Fourier Transform Infrared Spectroscopy
H <sub>2</sub> SO <sub>4</sub>	Sulphuric acid
H <sub>2</sub> O <sub>2</sub>	Hydrogen peroxide
HNO <sub>3</sub>	Nitric acid
ICP-OES	Inductively coupled plasma atomic emission spectroscopy
O	Oxygen
OPM	Oscillating Pressure Method
SEM	Scanning Electron Microscopy
SCCNFP	Scientific Committee Cosmetic Product and Non-food Products
Si	Silicon
TEM	Transmission Electron Microscopy
TTIP	Titanium Isopropoxide
Ti	Titanium
Ti <sup>4+</sup>	Titanium ( IV)
TiO <sub>2</sub>	Titanium dioxide
UV-spec	Ultraviolet-visible Spectrophotometry
UV	Ultraviolet
λ <sub>max</sub>	Lambda max
VOC	Volatile Organic Compounds

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# SYNTHESIS AND CHARACTERIZATION OF TITANIUM DIOXIDE NANOPARTICLES IN WOOD PROTECTION APPLICATION

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## ABSTRACT

Wood is an indispensable tool for human due to its aesthetic value, its properties and availability functions. However, wood will be degraded by microbes or termites. There were many studies for wood protection in the aspect of termite resistance, decay resistance, antibacterial, antifungal and chemical leaching. For example, wood timber is also being treated with inorganic biocides (copper based complex with chrome or arsenate). Their release could cause pollution to the environment. As alternatives, environmentally friendly organic biocide (e.g. emulsion of organic biocides and copper salt) and engineered nanomaterial have been investigated. In this study, the titanium dioxide nanoparticles synthesized were non-uniform in sizes or irregular shapes and, not well-dispersed and the mean sizes of dialyzed titanium dioxide nanoparticles were in the range of 6 nm to 10 nm. Titanium dioxide nanoparticles produced were impregnated within the *Dyera costulata* (Jelutong) wood blocks through vacuum impregnation, the results showed there was low leaching rate of titanium dioxide nanoparticles leached out from the wood block over two weeks which was detected by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES).

**Keywords:** Inorganic biocides, Titanium dioxide nanoparticles, Leaching rate

## ABSTRAK

Kayu adalah alat yang sangat diperlukan untuk manusia kerana nilai estetikanya, sifat-sifat dan fungsi ketersediaannya. Walau bagaimanapun, kayu akan diuraikan oleh mikroba atau anai-anai. Terdapat banyak kajian untuk perlindungan kayu dalam aspek ketahanan anai-anai, tahan reput, anti-bakteria, anti-kulat dan larut lesap kimia. Sebagai contoh, kayu juga dirawat dengan racun hidupan bukan organik (kompleks berasaskan tembaga dengan krom atau arsenate). Pembebasan mereka boleh menyebabkan pencemaran kepada alam sekitar. Sebagai alternatif, biosid organik mesra alam (seperti emulsi daripada biosid organik dan garam tembaga) dan nanomaterial kejuruteraan telah diasas. Dalam kajian ini, nanopartikel titanium dioksida disintesis adalah tidak seragam dalam saiz atau bentuk yang tidak teratur dan tidak tersebar dan purata saiz dialyzed titanium dioksida nanopartikel adalah dalam lingkungan 6 hingga 10 nm. Nanopartikel titanium dioksida yang dihasilkan telah memasukkan ke dalam *Costulata Dyera* (Jelutong) blok kayu melalui penghamilan vakum, keputusan menunjukkan terdapat kadar larut lesap rendah nanopartikel dioksida titanium terlarut lesap dari blok kayu dalam dua minggu yang dikesan oleh Pasangan Plasma Induktif Optik Pelepasan Spektrometri.

**Kata Kunci:** Biosid tak organik, Partikel nano titanium dioksida, Kimia larut lesap

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## 1.0 INTRODUCTION

From many years ago, wood acts as the main material of furniture, monuments and decorations which has the close relationship with human. However, fungi play a considerable role in the deterioration of wood, which contribute a lot in the field of cultural heritage, as their contamination favors the decay of the materials used for historical art objects. Fungus prevention, the treatment of wood objects and the conservation work have been done as restorers. Over the past decade, nanotechnology has been applied in several fields of cultural heritage conservation, for example the chemical degradation of mural paintings and paper acidity. Various wood protection applications have been mapped out to reduce the wood waste and also prolong the life span of a specific wood type. In common, architectural coatings are used to enhance the durability of wood in exterior environment (*Architectural and Industrial Coatings Solutions*, 2012). The architectural coatings usually used are inorganic UV absorbers since they increase the polymer stability.

On top of that, according to *Nanotechnology in the service of wood preservation (n.d.)*, wood timber is also being treated with inorganic biocides (copper based complex with chrome or arsenate). Their release may cause pollution to the environment. As alternatives, environmentally friendly organic biocide (e.g. emulsion of organic biocides and copper salt) has been investigated. At the same time, there is also research on wood protection which focused on process to impregnation metal oxides nanoparticles into wood. Perhaps, the combination metal oxides nanoparticles and organic biocides have the potential to preserve the natural colour of the wood and stabilize it against degradation by sunlight, fungi, moisture, etc.

Besides, according to Evans *et al.* (2008), the scientific community is not giving very much of interest to this large-scale commercial use of nanotechnology for wood protection even though there is a lot of contribution in the improvement of wood and other cellulose materials. The reason might be very few scientists are working in this field and they lack of experience in the use of metal oxide nanoparticles for wood protection.

The control of particle size, the structure and as well as the morphology of nanoparticles in synthesizing of nanoparticles are very important. There are various numbers of techniques available to synthesize different types of nanomaterial such as in the form of clusters, powders, colloids, etc. Some important techniques are including, chemical method, physical method, biological method, as well as hybrid technique (Khan *et al.*, 2011). However, the common ways to synthesize nanoparticles nowadays are the sol-gel process and hydrolysis reaction of glycol solution of alkoxide. While in the aspect of characterization, the techniques commonly used are Fourier Transform Infrared Spectroscopy (FTIR), UV-Spectrophotometer while the surface morphology is characterized by Transmission Electron Microscope (TEM) and Scanning Electron Microscopy (SEM). Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) is also used to determine the concentrations of titanium dioxide nanoparticles that have leached out to the deionized water.

The problem statement of this study is the use of titanium dioxide nanoparticles could leach out from the wood and serve as alternative to inorganic biocides (copper based complex with chrome or arsenate) as wood preservatives since the wood timber treated with inorganic biocides (copper based complex with chrome or arsenate) causes pollution to the environment.

The objectives of this research project are to synthesize titanium dioxide nanoparticles by using an appropriate method and to characterize the physical and chemical properties as well as the morphology of these nanoparticles as well as to determine the chemical leachability of the wood species of *Dyera costulata* (Jelutong) which has been impregnated with titanium dioxide nanoparticles.

## 2.0 LITERATURE REVIEW

Wood plays important role in our lives since it can be used for furniture and building purposes. However, wood can be decomposed by fungi or insects especially in tropical and tropics countries. There were several studies have been done for wood protection applications. According to Uekawa *et al.* (2012), nanoparticles, titanium dioxide is applied to many fields, for example photodynamic therapy, development of photocatalysts and semiconductors UV-shielding materials, electric devices and solar cells on woven and knitted fabrics for antibacterial activity.

### 2.1 Titanium Dioxide

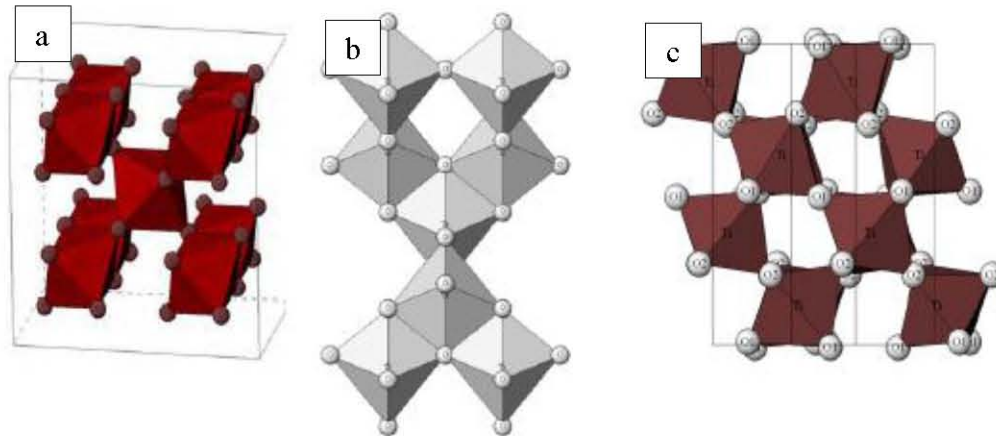


Figure 2.1.3: Structures of  $\text{TiO}_2$  crystals in the form of: a.) Rutile, b.) Anatase and c.) Brookite (Nolan, 2010)

Titanium is one of the elements that abundantly found on Earth and it is often found in ore minerals more than in its elemental state (Nolan, 2010). The ore minerals that consist of titanium are brookite, anatase and perovskite. However, only the first three are main polymorphs of titanium dioxide ( $\text{TiO}_2$ ) that will form different octahedral structures such as tetragonal and orthorhombic structures as shown in Figure 2.1.3. Titanium dioxide is chemically and biologically stable, non-toxic, inexpensive and has strong properties of oxidation (Missler & Tarr, 2011; Shriver & Atkins, 2001; Yun, 2013).  $\text{TiO}_2$  has the ability

to show high transparency and photocatalytic activity by cleaning up organohalides found in ground water and environmentally friendly (Begum and Ahmed, 2008).

### **2.1.1 Differences between Titanium Dioxide Nanoparticles and Titanium Dioxide**

According to Titanium Dioxide Stewardship Council (2012), compared to titanium dioxide, titanium dioxide nanoparticles were good protective materials for sunscreens because the primary particles sizes were small and higher surface area as well as it is transparent.  $\text{TiO}_2$  was a nanomaterial that is produced with primary particles sizes less than 100 nm and the manufacturing of various compounds of improved effective was allowed. Besides, it was not used as a colorant as its function was different from normal titanium dioxide size particles (Boffetta *et al.* 2004).

### **2.1.2 Benefits of $\text{TiO}_2$ as a Pigment and as Nanomaterial**

Based on Titanium Dioxide Stewardship Council (2006) and Boffetta *et al.* (2004),  $\text{TiO}_2$  in pigment form has the ability of UV light absorbance good in light scattering properties and white opacity with brightness were required to use in wide variety of applications. Titanium dioxide in pigment form could conjugate into polymer to protect the system from degradation. The effects were prolonging the lifespan of the paint and improve the protection of the solids in paint as well as the coating system. According to Chen & Fayerweather (1988), as a nanomaterial,  $\text{TiO}_2$  appears transparent as well as able to provide UV light absorption which allowed it function in the production of light stabilization for wood coatings and sunscreens. Environmental pollutants can also be decomposed via photocatalysis by  $\text{TiO}_2$  nanoparticles.  $\text{TiO}_2$  in the form nanomaterial was used as a DeNOx catalyst support in exhaust gas system in cars, trucks and power plants, thus minimizes their environmental consequences.

### **2.1.3 Structures of Titanium Dioxide Nanoparticles Produced**

There are various structures of titanium dioxide nanoparticles with different properties can be produced by different solvents such as methanol, ethanol and isopropanol and titanium tetraisopropoxide acts as a precursor.

Based on Mahyar and Amani-Ghadim (2011), TiO<sub>2</sub> nanoparticles prepared in isopropanol displayed pure anatase crystalline phase with the smaller sizes but had a greater pore volume and pore size which led to higher photocatalytic activity resulted by nitrogen physisorption. However, the TiO<sub>2</sub> nanoparticles prepared in methanol and ethanol contained anatase- and rutile-mixed phases with anatase larger crystallite sizes. TiO<sub>2</sub> nanoparticles prepared with ethanol had the lowest specific surface area but the greatest pore volume and pore diameter. The higher photocatalytic activity of the TiO<sub>2</sub> nanoparticles prepared in ethanol was attributed to its greater pore volume and pore size as well as the mixed anatase and rutile crystalline phases.

### **2.2 Barriers of Titanium Dioxide in Wood Protection**

In the aspect of wood protection, based on Jerneja *et al.* (2011), there was a study regarding the durability of wood in the external environment can be enhanced by titanium dioxide as an architectural coatings. However, according to Lu *et al.* (2003) mentioned there were two types of limitations in this area. Firstly, TiO<sub>2</sub> nanoparticles as catalyst, especially in anatase, crystal form and reduced rutile form will produce highly reactive free radicals and exhibit strong oxidizing power when absorbing UV lights, which was dangerous for photostability of polymer materials. Secondly, by producing suitable nano composites, the nanoparticles have to be dispersed without agglomeration in organic binders. The reason was nanoparticles have very high tendency to agglomerate due to their very large surface area to particle-size ratio. The problem of agglomeration has to be overcome by many efforts.

### **2.3 Alternative Way to Use Metal Oxide Nanoparticles for Inorganic Biocides Used Nowadays**

According to Marzbani and Mohammadnia (2014), the use of inorganic biocides such as Chromated Copper Arsenate (CCA) wood preservatives has been limited in European countries and United States due to the increasing awareness regarding dangers of using toxic chemicals in the wood preservation. Previously, there were many variety of inorganic biocide (Ag and Cu series) used for mold inhibition. Biocides were only effective for short-term antifungal purposes and toxic. Nowadays, photocatalytic oxidation has been extensively studied for removing various chemical and biological pollutants (Fujishima and Honda, 1972). As a commonly used photocatalyst,  $\text{TiO}_2$  was low mammalian toxic, non-volatile and environmentally friendly.  $\text{TiO}_2$  has been proved to be effective for not only microorganism disinfection, but also volatile organic compounds (VOCs) and odours or deleterious gases decomposition (Chen *et al.*, 2009).

### **2.4 Human Health Concerns with $\text{TiO}_2$**

In the aspect of inhalation, there was a lot of safety and precautions have been taken place including engineering control and personal protection equipment that have been applied in workers exposure control and worker risk mitigation as workers at titanium dioxide engineering plants will be exposed to  $\text{TiO}_2$  dust (Ramanakumar *et al.* 2008). The exposure of  $\text{TiO}_2$  dust to consumer was assumed to be very small because  $\text{TiO}_2$  was classically penetrated into the inner layer of the product was strongly bound such as in plastics or paints. Thus, inhalation exposure rate to general public is not considered serious. In oral intake,  $\text{TiO}_2$  meets appropriate purity standards were approved as a colorant for use in foods and pharmaceuticals.

According to Monteiro Riviere (2011) in the aspect of skin contact,  $\text{TiO}_2$  in pigment form or in nanomaterial form was used as cosmetic applications, such as lipstick, make-up



products and sunscreens. Study proved sunscreen containing  $\text{TiO}_2$  was safe to keep the skin from dangerous UV radiation. Results showed there is no harmful effects in the penetration of  $\text{TiO}_2$  nanoparticles from the sunscreen formulations even the skin was sunburned (SCCNFP, 2000). The former European Scientific Committee of cosmetic products and non-food products mentioned that the maximum percentage concentration of  $\text{TiO}_2$  is 25 % in order to keep the skin from certain destructive effects of UV radiation. The former European Scientific Committee on cosmetic products and non-food Products (SCCNFP) mentioned that the results in maximum concentration of 25% in order to keep the skin from certain harmful effects of UV radiation.

## **2.5 Synthesis of Titanium Dioxide Nanoparticles**

In the aspect of synthesise of nanoparticles, according to Umme *et al.* (2011) different types of nanoparticles in the form of colloids, cluster powders could be synthesis by various techniques, such as chemical method , physical method, biological method as well as hybrid technique. Similarly, this was also applied for the structure as well as morphology as according to Mishra *et al.* (2008). According to Wang *et al.* (2008), these properties were strongly influenced by the synthesis process. Nowadays, preparation of  $\text{TiO}_2$  nanopowders was reported by using various methods, including thermal hydrolysis, precipitation, hydrothermal, solvothermal, chemical vapour deposition and sol–gel process.

Among them, sol–gel process was an effective way to prepare  $\text{TiO}_2$  nanoparticles since the nanoparticles formed were pure and homogeneous, as well as large specific surface area (Wang *et. al.*, 2008). Based on Yu *et al.* (2003), performance of sol-gel process which was considerably depends on the process conditions such as pH, water/alkoxide ratio, type of precursors and reagents, calcination temperatures, reaction and mixing conditions have been reported by researches. Based on Maurizio *et al.* 2005,  $\text{TiO}_2$  nanoparticles produced by this method were amorphous in nature. Preparation of titanium dioxide nanoparticles by

sol gel process was generally used, due to its low cost equipment and low temperature required.

On the other hand, in hydrolysis reaction, the samples derived from  $\text{TiCl}_4$  were very photoactive and the process was not involving filtration and calcination in order to obtain highly efficient anatase phase. The structure of obtained titanium dioxide nanoparticles formed was affected by the concentration of  $\text{NH}_3$  aqueous solution (Uekawa *et al.*, 2012). According to Maurizio *et al.* (2005), the obtained sol was very stable without agglomeration of particles or gels as  $\text{TiCl}_4$  will not lead to the formation of impurities in the final product. The titanium dioxide nanoparticles obtained showed an enhanced adsorption towards the cationic dye molecules (Zaki *et al.*, 2010).

In the aspect of hydrothermal method, the hydrothermal method was different from sol gel process in the aspect of crystallite size, crystallinity, band gap, structural properties.  $\text{TiO}_2$  nanoparticles prepared via sol-gel process exhibit high luminescence than hydrothermal derived nanoparticles due to the chemical instability during fabrication process. In sol gel process, the  $\text{TiO}_2$  nanoparticles produced were highly crystalline and had smaller crystallite size as compared to the one prepared by hydrothermal method (~ 17 nm). The band gap of the synthesized nanoparticles was found to be size dependent.

## **2.6 Characterization of Titanium Dioxide Nanoparticles**

Based on the research from Alem *et al.* (2009) titanium dioxide nanoparticles was an n-type oxide semiconductor that exhibit photoconductivity and photocatalytic activity in UV-shielding materials, solar cells, and electric devices. Titanium dioxide nanoparticles were high wettability or superhydrophilicity. These properties can be applied in mirrors, since mirrors with coating  $\text{TiO}_2$  consists of antifogging function. Therefore, various glass

products such as mirrors and eyeglasses now can be imparted with antifogging properties by using this technology, with low cost processing fees (Fujishima *et al.*, 2002).

According to Fujishima *et al.* (2000), the environmental contaminants will be decomposed by TiO<sub>2</sub> nanoparticles as a photo catalyst. Nano-TiO<sub>2</sub> particles were high photocatalytic efficiency, biological and chemical inertness with tremendous UV resistance, low cost, favourable mechanic chemical properties and stability against photo corrosion. Purification of wastewater can be developed by TiO<sub>2</sub> nanoparticles based on photocatalytic processes as organic compounds can be broken down by photocatalytic process. For example, if one put catalytically active nano-TiO<sub>2</sub> powder into a contaminated water and allows it to be exposed to the sunlight, the water will be slowly purified. Besides, self-cleaning window glass and self-cleaning paint was containing titanium dioxide nanoparticles have been developed (Fujishima & Zhang, 2006).

## **2.7 Past, Present and Future of Wood Protection Industry**

Wood was an indispensable tool for our human and it has been history for our mankind. In our grandmother generation, wood has been used for cooking and building their house, even nowadays, the market demand for the wood is very high. Wood was used frequently for external building applications during the industrial technology advanced especially for the period of Industrial Revolution. However, wood does not inherit decay resistance properties due to the biological attack, such as termites, fungi and bacteria. According to Hunt and Garratt (1967), many processes have used to treat wood in the past, such as Oscillating Pressure Method (OPM), rapid cyclical oscillation between vacuum and pressure was employed to treat refractory wood species in Australia. Based on Freeman *et al.*, 2003, Alternating Pressure Method (APM), was also established to treat green or partly seasoned wood with Chromated Copper Arsenate (CCA).

Presently, vapour phase boron treatments function as main treatments for wood and wood based materials (Murphy *et al.* 2002). The main benefits of the method were reckless and hygiene of treatment and able to dry, handling and conditioning in a single vessel.

In future, wood will be protected by Engineered Wood Composites (EWC). According to Vlosky and Shupe (2002), the influence of the biocide on the chemical interaction with the resin, the physical properties of the compound, the dissemination of biocide within the product, the effectiveness of the treated composite, and the result of manufacturing on EWC properties have to be considered by using the combination of biocide and EWC. Effects of moisture and moisture temperature altered have to be minimized in the aspect of dimensional stability by modifying wood properties.

## **2.8 *Dyera costulata* (Jelutong) Wood Species**

According to Meding *et al.* (1996), Jelutong, *Dyera costulata* was a type of wood growing in South-East Asia. It was soft and easy to work and was used in, e.g., model workshops in car factories. It has also been much used in woodwork teaching in Swedish comprehensive schools but its wood dust causes contact allergy, as a result, the school was recommended to use a safer wood species as an alternatives for teaching.

## **2.9 Chemical Leaching**

Previously, chemical leaching was used to test the leaching concentrations of Chromated Copper Arsenate (CCA) wood preservatives since this inorganic biocide impregnated into the wood will pollute the environment. According to Weis *et al.* (1998), studies have been conducted to expose marine organisms to Chromated Copper Arsenate (CCA) treated wood or leachate waters. The results have shown against a range of aquatic organisms. According to Desch and Dinwoodie (1996), one of the major problems was lacking of understanding of long-term leaching rates, so the recommended preservative loading was

presently set at very high levels. There were factors to influence the leaching of chromium, copper and arsenic from disposed Chromated Copper Arsenate (CCA) treated wood, such as pH of the leachate, temperature, duration of the leaching and types of leaching agent (Moghaddam and Mulligan, 2008).

## **2.10 Penetration of Nanoparticles into the Dry Wood**

There was different effectiveness in various impregnation methods used. Firstly, the capillary pressure technology was the basis of the liquid flow through the wood was spraying, brushing, infusion and dipping under the atmospheric pressure. Secondly, the flow of liquids through the wood structure will be accelerated by the technologies where created pressure gradient such as vacuum-pressure, vacuum and pressure impregnation (Johnson & Kamke, 1992).

## **2.11 Factors that Influence the Penetration of Nanoparticles**

The wood absorptivity to liquids, the penetration methods and physiochemical properties of specific types of nanoparticles were dependent on the actual impregnation of nanoparticles. The penetration of nanoparticles was influenced by its viscosity which was related to the relative molecular weight of the nanoparticles (the size of its molecules) and the concentration of its solution. The constant viscosity of the nanoparticles and the increased of the molecular weight of the nanoparticles decreased the penetration of nanoparticles. In fact of impregnation based on the polarity, capillary action as well as its wetting ability influences the penetration of nanoparticles. An appropriate impregnation method must be chosen in correspondence with the degree of decomposition of a given wooden object. Therefore, a compromise between the molecular weight of the nanoparticles, the concentration and the viscosity of the solution and the solvent used have to been concerned to ensure nanoparticles penetrate into the damage wood (Drncova & Studium, 2011).

## **2.12 Do the Unique Properties of Nanometals affect Leachability or Efficiency against Fungi and Termites?**

According to Siegel (1999), due to the nanoparticles structure in the size range of 1-100nm, nanotechnology has developed in many applications, such as devices, materials or system. According to Clausen (2007), nanometal preparations were able to improve their performance in wood protection. Firstly, nanometals were created in a controlled particles size. Secondly, nanoparticles can be performed in high dispersion stability. Finally, nanometals preparations have a low viscosity. In conclude, due to these properties present, particles distribution was more uniform for greater penetration and protection over the wood surface. According to Kartal (2009), termite feeding was inhibited by nano-zinc and the study shows the evaluation of nanometals generally inhibit the white-rot fungus and were approximately will be effective in inhibiting the brown-rot test fungi.

## **2.13 Does Nanoparticle Activity Depend Upon Size and Crystal Phase?**

Various studies to establish the biological activity as well as the impact of physiochemical parameters such as crystal phase, size-surface properties and the others. For instance, the influence of size of the nanoparticles on biological activity, the mass of the sample on biological response and this should be done in toxicological studies and comparisons of the effects of different sizes of particles. According to Warheit *et al.* (2006), they have been several studies on the toxicity evaluation of nanosized titanium dioxide and a relationship to physico-chemical characteristics is established. For instance, three sizes of titanium dioxide nanoparticles were dosed by Warheit and co-workers to the lungs of rats and the results showed toxicity was independent upon particle size or surface area (Warheit *et al.*, 2006). However, anatase/rutile mixtures was the lowest oxidant reactivity presented by TiO<sub>2</sub> particles with similar size but different crystal morphology, followed by pure anatase, and highest was amorphous samples (Jiang *et al.*, 2008).

## **2.14 The Release of Engineered Nanomaterial to the Environment**

There are many impressive application prospects of nano-sized materials in various applications and our daily products and as a result, production of nanomaterial has been significantly increased (Royal Commission Report, 2008). However, potential impacts on human and environment of such material will be given a lot of attentions. According to Gottschalk (2011), nanomaterial could be emitted to three categories, which are free nanomaterial, aggregated nanomaterial or lastly is impregnated in a matrix. A previous study has proofed evidence for the release of nanomaterial into the environment from products containing nanomaterial. Results showed the nanomaterial are actually released but the quantifying what has been released is the main difficulties. Therefore, the composition within the products may be altered, but most importantly is the nanomaterial is still embedded in the matrix and not released as an individual particle.

## **2.15 Functions of Titanium Dioxide Nanoparticles in Wood Protection**

The UV transmission radiation can be absorbed by nano-titanium dioxide and its photocatalytic properties provide antibacterial coatings (Daoud *et al*, 2005). The antifungal properties of titanium dioxide by using *Aspergillus Niger* fungal cultivation and UV irradiation have been studied by Chen *et al.* (2009). Results showed that the TiO<sub>2</sub> coated film in the presence of UVA (365nm) radiation exhibited antifungal capability. Saha *et al.* (2001) used nano- TiO<sub>2</sub> to coat the surface against UV radiations. The result showed that there were no significant influences on wood colour when the titania embedded with UV absorber coating has applied but the adding of lignin stabilizer plays an significant role in protection of wood against UV exposure. According to Shabir *et al.* (2013), titanium dioxide nanoparticles exhibited decay resistance and this was affected by the amount of titanium dioxide present in the wood structure. The result was showing the wood treated

with low concentration titanium dioxide solution was more decay resistant than the wood treated with higher concentrations.

## **2.16 Acid Digestion**

According to Ghanthimathi *et al.* (2013), acid digestion was used to transform solid samples such as sawdust into liquid phase and undergoes digestion whereby the organic components are destroyed by acid releasing metals that were dissolved into solution that can be analyzed spectroscopically.

There are various types of acid digestion, such as microwave assisted acid digestion. In the investigation of Soylak *et al.* (2004), microwave assisted acid digestion procedures are gaining popularity recently due to the speed of the digestion process as well as less possibility of contamination during the process.

Microwave digestion procedures have the advantages of short digestion time, less acid consumption and high extraction efficiencies in making them preferable when compared with the conventional methods (Ghanthimathi *et al.* , 2013) .

## **2.17 Leaching Rate**

According to Lebow (1996), there were various factors to influence leaching rate, such as exposure time, surface area, wood species and preservatives components. For wood species, there was high leaching rate for a more permeable wood because of the rapid movement of leachate. However, Kennedy and Palmer (1994) also noted that the leaching of CCA may be greater from heartwood than sapwood because heartwood extractives restrict with the fixation process.